

# AN INVESTIGATION OF TWENTY-ONE SASKATCHEWAN BALL CLAYS<sup>1</sup>

By W. G. WOODWARD<sup>2</sup>

## ABSTRACT

Twenty-one Saskatchewan ball clays have been investigated; the study covers in a general way their chemical, raw, and fired properties. The information presented will no doubt prove of immediate interest to the ball clay trade and especially to the Saskatchewan shippers and exporters.

In general, the more outstanding properties of the clays studied are raw strength, fired color, crack resistance, and rate of vitrification.

Their raw strength is remarkably high, greater than that of any similar clay on the market at the present time. One clay developed the exceptional raw strength, though diluted with 30% potters' flint, of over 1000 lbs. per square inch, a second one 938 lbs., while the average of the eleven highest is 812.8 lbs.; clays of such high strength should prove of interest to the trade where it is desirable to reduce losses in the raw and bisque state.

A number of the clays tested are outstanding as ball clays in that they fire white or nearly so up to and including cone 12, the purity of whiteness being equal to that of white firing china clays.

The porosity and fired volume shrinkage of the Saskatchewan clays corresponds more nearly to those of the English ball clays than do the Tennessee-Kentucky clays as studied by Scottwell.

## Introduction

Information concerning the clays of Saskatchewan that fire to a light color has been meager. The existence of these clays has been known for many years. Dr. Bell<sup>3</sup> made mention of them in his report on the coal seams of the Dirt Hills (Sask.). It is not likely that Dr. Bell attached any importance to the clays.

The first test of the Saskatchewan light clays was conducted in 1907 by Edward Orton, Jr., on twenty-seven samples of clay collected from the Dirt Hills by Daniel Diver.<sup>4</sup>

The first official report of these clays was given by Ries and Keele.<sup>5</sup> This was followed in 1918 by a more detailed report by N. B. Davis.<sup>6</sup>

The work of Davis awakened a ceramic interest in Saskatchewan and this led to the establishment of the Ceramic Department at the Saskatche-

<sup>1</sup> [Presented for use at the Annual Meeting, AMERICAN CERAMIC SOCIETY, Chicago, Ill., February, 1929. (White Ware Division.) Received January 2, 1929. This publication does not constitute a release to the press.]

By permission of the Deputy Minister, Department of Railways, Labour, and Industries of the Saskatchewan Government, Regina, Sask.

<sup>2</sup> Prof. Ceramic Eng., Univ. of Sask., Saskatoon, Sask.

<sup>3</sup> Dr. Bell, Report of Progress, Geological Surv. Can., 1873-74.

<sup>4</sup> Prospector.

<sup>5</sup> Ries and Keele, *The Clay and Shale Deposits of the Western Provinces*, 1912.

<sup>6</sup> N. B. Davis, Report on the Clay Resources of Southern Sask. Dept. of Mines, Canada.

wan University in cooperation with the Department of Railways, Labour, and Industries of the Provincial Government, the activities to be not wholly academic but also to conduct surveys and research work on the clays of the province.

A study of twenty-one Saskatchewan ball clays was one of the surveys made.

The field collection of the samples and much of the research was completed in 1924. All samples and records were destroyed in the disastrous fire at the University in 1925.

### The Laboratory Investigation

#### Preparation of Samples

Care was used to procure an average sample of each clay at the deposit. On arrival at the laboratory they were allowed to room dry. One hundred pounds of each were crushed in rolls, slowly fed into a tank of water, and soaked for 24 hours, then thoroughly blunged, screened through a 180-mesh

Tyler brass screen, allowed to settle, the excess water siphoned off, the slip thoroughly stirred and forced into a filter press by compressed air. The filter-pressed cakes of each were dried to a point where they could be re-crushed and dry screened through 8-mesh, the batch thoroughly dry mixed, water added, and the mass wedged on plaster and packed into large stone-ware jars, covered, and allowed to age for forty-eight hours. After re-wedging all trial pieces were prepared in as short a time as possible, the same assistant making the same trial pieces from clay to clay, thus avoiding insofar as possible any variations. To further avoid chances of error

there were made ten trial pieces for each test or measurement and the average taken as the final figure.

**Tests Made** The tests made were as follows:

(1) *Chemical*: Six clays were selected for this.

(2) *Elutriation*: The percentage and size of particles in each sample finer than 20-mesh were determined. The apparatus used was patterned after Schultz, though the construction and operation followed Krehbiel.<sup>7</sup>

(3) *Hydrogen-Ion Concentrations*: The values for the several clays were determined in a La-Motte roulette comparator. A quantity of

<sup>7</sup> *Trans. Amer. Ceram. Soc.*, 6, 173-85 (1904).

ground clay was placed in a quart fruit sealer with sufficient distilled water to make a thin slip, the sealer placed in the frame of a ball mill in such a position that at each revolution of the mill the clay slip was thrown or splashed from end to end of the sealer for two hours. The clay was then allowed to settle and the determinations made.

(4) Water of Plasticity: The samples were hand pressed in a steel mold, 11 by 1 by 1 inch, and cut into trials,  $2\frac{1}{2}$  by 1 by 1 inch. They were weighed immediately and, after drying at  $110^{\circ}\text{C}$ , cooled in a desiccator.

(5) Per cent of Shrinkage and Pore Water: These were determined by the Standard Method of the AMERICAN CERAMIC SOCIETY.

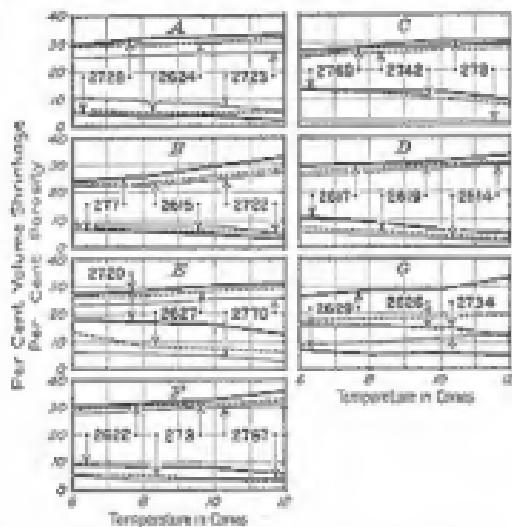


FIG. 2.

The wet and dry volumes were taken of the trial pieces used in obtaining the water of plasticity, thus it was only necessary to apply the following formulas:

$$\text{Shrinkage water} = t_s = \frac{V_p - V_d}{W_d} \times 100$$

Where  $t_s$  = the percentage of shrinkage water

$V_p$  = the plastic volume in cu. cm.

$V_d$  = the dry volume in cu. cm.

$W_d$  = the dry weight in grams

$$\text{Pore water} = t_p = T - t_s$$

Where  $t_p$  = the percentage pore water

$T$  = the percentage water of plasticity

(6) Volume Drying Shrinkage: The volume drying shrinkage was determined on trial pieces,  $1\frac{1}{2}$  by  $1\frac{1}{2}$  by  $1\frac{1}{2}$  inches. The freshly made trials were placed at once into a kerosene bath, their green volume mea-

suted in a Schurecht overflow volumeter, room dried at 65°C and 110°C, and cooled in a desiccator, soaked in oil for 24 hours, and their dry volume taken as before. The percentage of drying shrinkage was calculated on the wet volume.

(7) *Transverse Strength of the Raw Clay:*\* Ten bars, 6 by 1 by 1 inch, were made of each clay in its raw plastic state; in addition, a second portion was dried, pulverized, and carefully blended with 50% potters' flint, tempered, and then made into trial pieces similar to the above. All of these were dried at room temperature and finally at 110°C, cooled in a desiccator and broken transversely; the moduli of rupture were calculated by the usual formula.

(8) *Transverse Strength—Clay-Flint Mixture:* For this test the clays were first blunged and screened through 100-mesh, dried at 65°C, crushed through a 20-mesh screen, then blended with potters' flint in equal parts by weight. The mixture, after tempering, was thoroughly wedged and allowed to age for 24 hours. Twenty trials, 1 $\frac{1}{4}$  by 1 $\frac{1}{4}$  by 1 inches, were then molded, room dried and finally dried at 65° and 110°C. Ten of them were cooled in a desiccator followed by cross-breaking in a simple lever-type machine, using running shot to apply the load, 100 lbs. per minute. The remainder of the trials were fired in a commercial brick kiln to cone 8 and then broken in the same manner as the raw trials.

(9) *Volumic Firing Shrinkage:* Forty trials, 1 $\frac{1}{4}$  by 1 $\frac{1}{4}$  by 1 $\frac{1}{4}$  inches, were prepared from each clay, their wet and dry volumes were taken, then ten of each were fired to cones 6, 8, 10, and 12 and their fired volumes determined, the per cent of shrinkage being calculated as per cent on the wet and dry basis.

(10) *Absorption and Apparent Porosity:* Sets of ten trials of each clay, 1 $\frac{1}{4}$  by 1 $\frac{1}{4}$  by 1 $\frac{1}{4}$  inches, were prepared for firing at cones 4, 6, 8, 10, 12, and 14, in an updraft muffle kiln fired with oil, the firing periods ranging from 30 to 40 hours. The trials were weighed at once when taken from the kiln, then placed in water with one face exposed for twenty-four hours, the water brought up to and held at boiling point for two hours, then allowed to cool, each trial wiped free of excess water, and weighed. The per cent absorption was calculated on the dry weight. The suspended weight in water was taken of the absorption trial pieces that the per cent apparent porosity could be calculated by Purdy's formula:

$$P = \frac{W - D}{W - S} \times 100$$

Where  $P$  = per cent apparent porosity

$W$  = weight of the saturated test piece

$D$  = " " " dry-fired " "

$S$  = suspended weight of the fired test piece

\* It was found, with two or three exceptions, that the clays could not be dried free of checks; therefore the results were very misleading and are not published.

(11) *Apparent Specific Gravity:* The figures for the apparent specific gravity of the several clays were obtained from the dry and suspended weights of the fired volume shrinkage trials, using the formula and method of Purdy.<sup>9</sup>

$$\text{Apparent specific gravity} = \frac{\text{Dry weight}}{\text{Dry weight} - \text{susp. weight}}$$

(12) *Transverse Strength after Firing Clay-Flint Mixture:* Ten trial pieces of each clay were fired at cone 8 in a commercial firebrick kiln. Upon their return to the laboratory they were placed in a drying oven for twenty-four hours, cooled in a desiccator, then broken transversely, and their moduli of rupture determined by the usual formula.

(13) *Color after Glazing:* Disks of the plastic clay were jiggered in plaster molds  $\frac{1}{8}$  inch deep and 10 inches in diameter. The disks were cut with a 3 $\frac{1}{2}$ -inch diameter-cutter into the desired trial pieces and dried away from dust, then fired at cones 4, 8, and 12. Five of the trials from each firing were glazed with a Standard borosilicate glaze kindly supplied by the Housler-Laughlin China Company of Newell, W. Va. The trials were then placed in saggers and fired in a muffle kiln to cone 2 in twelve hours.

(14) *Resistance to Cracking:* The glazed trials of each clay used in the color study were placed in an electrically heated oven having a thermo-static control capable of maintaining a temperature within  $\frac{1}{2}^{\circ}\text{C}$ . The temperature was held at  $223^{\circ}\text{C}$ , being a spread of  $210^{\circ}\text{C}$  from that of the water used for quenching. After the oven and trials had been held at the desired temperature for one hour the trials were taken from the oven and immersed at once into running water at  $13^{\circ}\text{C}$ . When the trials were at the water temperature they were at once returned to the oven. This was repeated five times.

(15) *Oxidation:* For this test briquets,  $1\frac{1}{2}$  by  $1\frac{1}{2}$  by 2 inches, were made, dried, and then placed in the muffle of an oil-fired kiln and raised steadily in temperature to  $730^{\circ}\text{C}$  in five hours and then held constant at that temperature. Trials of each clay were drawn hourly, though in a few cases at half-hour intervals, until the clay requiring the longest period of oxidation showed no further traces of unoxidized material. The time required for oxidation has been plotted for comparison against the results obtained by Sortwell<sup>10</sup> in a similar test on English and United States ball clays.

(16) *Fusion Test:* Cones were made of the several clays after washing. When dry the cones were calcined. The actual fusion determinations

<sup>9</sup> R. C. Purdy, Ill. Geol. Surv., Bull., No. 9.

<sup>10</sup> U. S. Bur. Stand., Tech. Paper, No. 237.

were made in a bottom-fired oxyacetylene furnace<sup>11</sup> as described by Gorton and Grover.

### Results

TABLE I

#### CHEMICAL ANALYSIS

Ceramic Dept. No.	2612	2622	2624*	2626*	2611	2618
Chemistry Dept. No.	66/37	66/37	66/37	66/37	66/37	71/37
Loss on ignition	11.60	12.460	12.02	9.16	10.30	12.45
Silica (SiO <sub>2</sub> )	56.92	51.284	54.31	65.14	54.49	55.03
Alumina (Al <sub>2</sub> O <sub>3</sub> )	28.96	32.70	29.77	28.87	28.89	29.35
Titania (TiO <sub>2</sub> )	1.02	0.68	0.76	1.05	0.75	0.82
Iron (Fe <sub>2</sub> O <sub>3</sub> )	0.85	0.69	0.81	0.73	0.79	0.90
Lime (CaO)	0.38	0.28	0.48	Trace	1.08	0.58
Magnesia (MgO)	0.25	0.31	0.45	0.33	0.62	0.35
Alkalies (Na <sub>2</sub> O)	0.21	0.43	0.50	0.10	0.02	0.23
Total	100.46	100.63	100.22	100.35	100.20	100.30

\* Unwashed.

TABLE II  
ELUTRIATION AND WASHING

No.	Per cent loss	Per cent loss	Per cent loss	Per cent loss	Per cent total losses	Per cent dry substance
No.	No. 1 loss	No. 2 loss	No. 3 loss	No. 1 loss		
2614	5.1	1.1	2.9	10.0	20.0	80.0
2615	5.5	2.5	5.4	5.4	21.0	78.4
2617	2.7	1.0	2.3	5.8	13.9	86.1
2619	5.5	2.0	5.1	5.4	20.7	79.3
2622	3.4	1.0	2.9	7.0	14.3	85.7
2624	5.5	0.8	4.5	5.5	19.3	80.7
2625	14.3	5.4	4.0	10.4	33.0	65.0
2627	3.2	0.0	3.5	10.0	10.7	89.3
2629	6.10	1.2	2.8	4.6	14.7	85.3
273	3.4	1.6	4.8	5.8	18.4	81.6
277	4.7	2.4	4.5	7.2	18.9	81.2
278	5.2	0.8	1.6	6.6	14.0	86.0
2720	42.1	1.8	1.5	1.5	43.9	53.1
2722	5.6	1.9	2.8	5.9	16.3	83.8
2723	2.9	5.2	4.3	8.0	23.4	76.6
2724	6.0	2.7	7.0	10.3	25.2	73.8
2734	4.8	5.7	7.2	11.1	26.8	71.2
2742	4.6	2.8	6.0	9.8	22.8	77.2
2767	5.0	2.1	1.5	2.7	11.3	88.7
2768	3.1	1.6	4.2	12.0	21.5	78.5
2770	5.1	0.0	3.9	10.6	20.7	79.3

TABLE III  
HYDROXIDE-ION CONCENTRATIONS

Clay no.		Clay no.	
2614	7.6	276	7.4
2615	7.0	2730	6.6
2617	6.6	2732	7.8
2619	6.6	2733	6.4
2622	6.8	2738	6.0
2624	7.0	2734	6.0
2626	7.2	2742	7.3
2627	7.0	2767	6.0
2628	7.7	2759	6.5
273	7.1	2770	6.2
277	7.4		

<sup>11</sup> *Jour. Amer. Ceram. Soc.*, 8 (11), 768-73 (1925).

TABLE IV  
PER CENT WATER OF PLASTICITY

Clay no.	Per cent			Per cent			Per cent		
	wet	dry	basic	wet	dry	basic	wet	dry	basic
2614	25.5	24.2	26.27	28.7	40.3	27.33	28.9	40.7	
2615	25.0	23.4	26.09	24.0	32.6	27.28	27.7	38.9	
2617	24.8	23.9	27.3	26.3	35.7	27.34	24.9	38.1	
2619	22.3	21.5	27.7	27.9	35.7	27.42	25.1	39.5	
2622	28.5	24.3	27.8	29.3	38.1	27.67	28.7	39.7	
2624	27.9	28.6	27.21	29.3	41.4	27.89	24.5	32.5	
2626	24.0	21.7	27.23	26.3	49.1	27.70	24.7	30.1	

TABLE V  
PER CENT PORE AND SHRINKAGE WATER

Clay no.	Per cent		Clay no.	Per cent		Clay no.	Per cent	
	pores	shrinkage		water	water		water	shrinkage
2614	10.62	17.00	276	15.10	26.40			
2615	10.64	15.80	2720	19.00	22.40			
2617	17.87	15.01	2722	11.46	22.24			
2619	7.85	20.95	2723	17.35	21.40			
2622	10.58	17.80	2728	18.65	21.75			
2624	12.12	23.35	2734	12.50	15.51			
2625	14.08	15.02	2742	14.88	18.91			
2627	14.18	25.20	2767	18.52	21.67			
2629	14.39	15.28	2769	16.75	15.30			
273	15.94	19.82	2770	15.81	17.30			
277	14.88	23.82						

TABLE VI  
PER CENT DRYING SHRINKAGE

No.	Volume shrinkage		Linear shrinkage		No.	Volume shrinkage		Linear shrinkage	
	Wet basis	Dry basis	Wet basis	Dry basis		Wet basis	Dry basis	Wet basis	Dry basis
2614	23.1	23.5	9.18	10.11	278	23.5	20.6	12.72	14.62
2615	23.4	20.5	8.90	9.28	2720	28.7	40.2	10.05	11.92
2617	22.0	20.7	8.30	9.06	2722	29.4	41.6	10.26	12.29
2619	27.3	28.0	10.29	11.49	2723	29.8	42.5	11.13	12.53
2622	24.8	30.0	9.06	9.97	2726	24.6	40.0	10.62	11.93
2624	31.3	40.7	11.95	13.02	2724	21.7	31.2	8.62	9.47
2626	23.7	31.0	8.62	9.43	2743	25.4	33.9	8.31	10.22
2627	23.3	49.9	12.63	14.44	2767	27.8	35.5	10.20	11.47
2629	25.7	34.6	8.42	10.41	2769	22.1	28.4	7.99	8.59
273	20.8	30.7	8.88	10.68	2770	24.2	31.9	8.82	9.67
277	20.5	41.9	11.00	12.37					

TABLE VII  
MODULUS OF BURSTURE OF UNREFINED TERRA

No.	Modulus of bursture		No.	Modulus of bursture		No.	Modulus of bursture		
	90% dry	90% wet		No.	90% dry		No.	90% dry	90% wet
2614	745	2627	938	2723	882				
2615	668	2629	757	2728	840				
2617	679	273	752	2734	661				
2619	652	277	727	2742	661				
2622	754	278	795	2767	1008				
2624	769	2790	409	2769	440				
2626	543	2723	612	2770	669				

TABLE VIII  
PER CENT LINEAR FIRING SHRINKAGE, WET AND DRY BASIS  
Cases 6, 8, 10 and 12

Clay no.	Wet basis	Dry basis						
2614	7.35	8.41	7.71	8.75	8.07	9.11	8.19	9.16
2615	8.23	7.20	6.40	7.29	7.00	7.98	7.32	8.38
2617	8.00	9.26	8.70	9.39	8.44	9.04	9.44	10.05
2619	7.28	8.61	7.71	9.03	7.87	9.20	8.19	9.20
2622	8.27	9.23	8.74	9.70	8.08	9.87	9.87	10.52
2624	7.12	8.92	7.17	8.94	7.40	9.20	7.83	9.04
2625	4.61	5.45	4.70	5.61	4.94	5.83	5.15	6.00
2627	6.25	8.10	6.31	8.21	6.78	8.72	6.91	8.30
2629	7.12	8.21	7.64	8.72	7.71	8.77	8.79	9.81
273	7.91	9.11	7.91	9.11	8.30	9.47	8.70	9.96
277	6.02	7.46	6.23	7.81	7.17	8.09	8.11	9.07
278	8.75	7.87	7.69	9.11	7.17	9.17	7.38	9.38
2720	6.90	8.35	7.17	8.73	7.87	9.31	7.91	9.34
2722	5.42	6.80	5.05	7.00	6.21	7.85	6.74	8.29
2723	6.10	7.61	6.92	8.01	6.03	8.16	6.82	8.45
2728	7.64	9.06	8.15	9.38	8.34	9.75	8.54	9.97
2734	2.38	2.85	2.67	3.29	2.88	3.24	2.81	3.91
2742	7.61	8.07	7.28	8.35	7.52	8.58	7.82	8.58
2747	6.60	8.24	7.32	8.05	7.79	9.14	8.20	9.04
2759	7.60	8.32	8.07	8.77	8.19	8.86	8.10	8.86
2770	6.14	7.09	6.33	7.29	6.82	7.78	6.90	7.87

TABLE IX  
PER CENT VOLUME FIRING SHRINKAGE ON WET AND DRY BASIS  
Cases 6, 8, 10 and 12

No.	Wet basis	Dry basis						
2614	21.5	27.4	21.4	26.8	22.3	29.8	22.6	29.2
2615	17.8	23.2	18.0	26.5	19.8	29.9	20.8	27.3
2617	20.4	20.4	23.3	20.9	24.5	21.5	23.7	23.3
2618	20.3	26.1	21.4	21.6	21.8	20.2	22.6	21.3
2622	22.8	26.3	24.0	22.0	24.8	23.0	26.3	35.0
2624	19.9	29.2	20.0	29.3	20.6	30.2	21.7	31.8
2626	15.2	17.3	15.6	17.8	14.1	18.5	14.6	19.1
2627	17.8	29.3	17.8	26.7	19.0	28.5	19.2	28.8
2629	19.9	26.7	21.2	25.5	21.4	25.7	24.1	32.4
273	21.9	29.9	21.9	29.9	22.9	31.2	23.9	32.6
277	17.0	24.1	17.8	25.3	20.0	28.4	22.4	31.9
278	18.9	25.5	19.4	26.8	20.0	26.1	21.5	30.9
2720	19.3	27.2	20.0	28.0	21.8	30.6	21.9	30.7
2722	16.4	21.8	16.0	22.6	17.5	24.8	19.0	27.0
2723	17.2	24.6	16.3	26.0	18.6	25.5	19.1	27.2
2726	21.2	29.7	22.5	31.5	23.0	32.2	23.5	33.0
2724	6.9	9.1	7.3	10.2	8.4	11.0	9.2	12.2
2743	10.6	26.2	20.3	27.2	20.9	29.0	20.9	28.0
2747	15.2	26.2	20.4	26.3	21.5	29.0	22.9	31.8
2758	21.1	27.1	22.3	28.7	22.6	29.0	22.6	29.1
2770	17.3	22.8	17.8	22.5	19.1	25.2	19.3	26.5

TABLE X  
PER CENT ABSORPTION

Clay no.	Cases 4	Cases 6	Cases 8	Cases 10	Cases 12	Cases 14
2614	3.39	3.31	2.14	3.57	0.98	0.59
2615	3.76	3.70	3.63	4.15	3.08	0.39
2617	5.21	4.93	4.57	4.02	2.41	1.57

Clay no.	Core 4	Core 6	Core 8	Core 10	Core 12	Core 14
2616	3.87	3.35	2.78	2.48	1.87	0.82
2619	5.70	5.42	4.11	3.90	1.66	1.34
2624	3.21	2.42	1.95	1.95	1.06	1.82
2626	8.22	8.10	8.15	7.08	5.88	3.48
2627	2.34	2.43	2.30	2.14	1.57	1.06
2629	3.25	2.41	2.34	2.02	1.86	1.71
273	3.04	3.19	2.31	2.01	1.12	0.81
277	3.65	4.72	4.28	3.92	1.68	1.04
278	0.34	0.52	0.42	0.40	0.21	0.20
2730	9.75	8.47	7.81	7.61	5.40	1.50
2732	5.80	4.76	4.32	4.09	3.14	1.84
2733	5.46	5.00	4.51	4.10	2.41	1.41
2735	3.57	2.30	1.45	1.42	1.33	1.23
2736	8.12	8.09	7.80	7.80	5.63	1.97
2742	6.15	5.82	5.00	4.09	2.05	2.58
2747	3.44	2.05	1.95	1.84	1.63	1.29
2759	6.22	5.15	4.72	4.57	3.41	2.43
2770	6.22	5.90	3.95	4.04	2.85	1.61

TABLE XI  
PER CENT APPARENT POROSITY

No.	Core 4	Core 6	Core 8	Core 10	Core 12	Core 14
2614	7.25	6.7	5.34	4.16	2.18	1.1
2615	12.43	8.97	7.04	7.13	5.82	0.88
2617	12.10	11.37	10.21	7.81	5.32	3.89
2619	8.23	7.03	6.26	4.23	2.65	1.00
2622	12.06	10.20	9.11	8.45	5.94	3.18
2624	7.0	5.93	4.30	4.30	4.20	4.13
2626	16.6	16.53	15.35	14.20	12.00	0.63
2627	5.02	5.41	5.00	4.62	3.62	0.76
2629	7.2	4.95	4.85	4.41	3.70	2.86
273	7.06	6.13	5.40	4.21	2.73	1.75
277	11.93	8.23	7.80	6.2	3.34	2.04
278	1.21	1.10	1.04	0.87	0.51	0.30
2720	19.9	17.70	16.60	12.5	11.80	3.40
2722	11.67	9.10	9.11	9.06	5.62	4.10
2724	11.83	10.80	9.61	9.21	6.22	3.18
2725	6.31	4.76	3.59	3.19	2.45	2.24
2734	16.33	16.19	15.7	13.7	11.42	4.13
2742	13.30	12.20	11.17	9.92	6.85	6.03
2747	7.40	5.15	4.35	4.05	3.30	2.79
2749	14.7	12.14	11.30	11.04	8.74	7.20
2770	13.23	12.50	8.80	7.85	6.70	4.80

TABLE XII  
APPARENT SPECIFIC GRAVITY

No.	Core 4	Core 6	Core 8	Core 10	Core 12
2614	2.16	2.21	2.26	2.30	2.37
2615	2.11	2.18	2.11	2.14	2.18
2617	2.20	2.25	2.27	2.24	2.32
2619	2.27	2.27	2.34	2.26	2.31
2622	2.21	2.21	2.24	2.25	2.28
2624	2.29	2.27	2.20	2.23	2.30
2626	2.03	2.05	2.01	2.05	2.09
2627	2.24	2.30	2.27	2.26	2.31
2629	2.23	2.23	2.26	2.25	2.33
273	2.24	2.23	2.24	2.25	2.30
277	2.11	2.24	2.20	2.14	2.27
278	2.60	2.47	2.44	2.41	2.43
2720	2.03	2.13	2.11	2.07	2.17
2722	2.13	2.25	2.22	2.21	2.22
2723	2.18	2.18	2.19	2.20	2.21

TABLE XII (Continued)

No.	Cone 4	Cone 6	Cone 8	Cone 10	Cone 12
2728	2.04	2.40	2.41	2.00	2.25
2734	1.97	1.98	1.99	2.00	2.02
2743	2.21	2.27	2.26	2.21	2.24
2767	2.18	2.29	2.27	2.27	2.26
2770	2.08	2.27	2.26	2.22	2.27
2770	2.19	2.24	2.27	2.24	2.26

TABLE XIII  
MODULUS OF RUBBER OF FIXED TRIALS, CONE 8  
(60% clay—50% flint)

No.	lb.	No.	lb.	No.	lb.
2614	2396.0	2627	1715.6	2723	2119.0
2615	2121.6	2629	2169.3	2728	2014.0
2617	2393.0	2731	2704.3	2734	1700.0
2619	1561.5	2737	2017.0	2742	2431.3
2622	2201.6	2738	2307.3	2767	2146.0
2624	2641.0	2750	1751.6	2769	1941.0
2626	2362.6	2752	2529.0	2770	2328.0

TABLE XIV  
COLOR AFTER GLAZING

No.	Cone 4	Cone 8	Cone 12
2614	Light cream; many small black specks	A darker shade of cream; specks more pronounced	A light bluish cream; specks more pronounced
2615	A clear light cream; specks just visible	A deeper shade of cream; many light brown specks	Practically the same as cone 8 trials
2617	A creamy white; a few dark specks	Same shade of white; specks numerous	Slightly darker shade; specks more pronounced
2619	A deep cream; numerous small specks	Slightly deeper shade; specks numerous	Bluestoned throughout; specks quite black
2622	Nearly white; specks can be seen only with a glass	A light cream white; few small yellowish specks	Practically the same as cone 8 trials
2624	Nearly white; specks seen only by use of a glass	Practically the same as cone 4 trials	Bluestoned throughout; a glass needed to see specks
2626	A light cream; a few specks just visible	Same shade as cone 4; specks most pronounced	A deep cream; numerous yellowish specks
2627	A medium cream; numerous specks showing	Practically the same as cone 4; specks are darker	Trials are starting to bluestone; specks same as cone 8
2629	A dark cream or ivory; a few specks showing	A much darker shade; specks quite pronounced	Bluestoned throughout; specks same as cone 8
273	A clear light cream; no specks	A much deeper shade; yellowish specks	Same as cone 8
277	A light ivory or cream; no specks	About the same shade; a few specks showing	A deep ivory and signs of bluestoning; a very few specks
278	A yellowish white with many specks	A light bluestoning; many specks	A deep bluestoning; many black specks

No.	Cone 4	Cone 8	Cone 12
2730	Light creamy white few specks	Slightly lighter shade specks more pronounced	Shade same as cone 4 though specks show more plainly
2733	An ivory tint, body speckled	Same as cone 4 trials	A darker shade, otherwise the same as cones 4 and 8 trials
2735	A clear light cream, no specks	Just a shade darker a few odd specks	Illustrated a few specks showing
2738	A light creamy white no specks	A darker cream color only an odd speck	Illustrated an odd speck or so
2734	A very deep clear cream no specks	A slightly lighter shade, yellowish specks show ing	A deep yellowish cream, specks same as cone 8 trials
2743	Nearly white, no specks	A slight cream tint and a few specks	Practically the same as cone 8 trials
2757	A light cream with light brown specks	A lighter shade though starting to bluestone	Bluestoned throughout, clear of specks
2759	A creamy white, free of specks	A deeper shade and specks showing	Practically the same as cone 8
2770	Nearly white free of specks	Name as shade, few specks showing	Shade only slightly changed, specks same as cone 8

## Best White or nearly White at

Cone 4	Cone 8	Cone 12
2611	2623	
2622	2629	2743
2624	2624	2770
273	2742	
2728	2789	
2742		
2749		
2750		
2770		

## Best Light Cream or Ivory at

Cone 4	Cone 8	Cone 12
2615	2619	2720
2619	2627	
2626	2627	
2627	271	
277	2720	
2720	2722	
2722	2723	
2723		
2727		

## Best Deep Cream or Ivory at

Cone 4	Cone 8	Cone 12
2734	2729	277
2734	2789	
2739	2734	
	2769	

## Bluestoned at

Cone 4	Cone 12	Cone 17
2738	2714	277 (slight)
2767	2619	278
	2624	2720
	2627 (slight)	2738
	2629	2777

## Clays Speck Free at

Cone 4	Cone 8	Cone 12
2622	2734	None
2624	2742	None
273	2759	
2734	2770	
2758		

## Clays Lowest in Species at

Cone 4	Cone 8	Cone 12
2615	2622	2767
2620	2624	2770
2629	277	277
2720	2722	2723
	2724	2725
	2642	2743
	2667	2770

TABLE XV  
RESISTANCE TO CRAZING

No.	Case I	Case II	Case III
21-4	20% S.C. 80% N.C.	100% N.C.	60% S.C. 40% N.C.
21-5	20% S.C. 80% N.C.	100% N.C.	20% S.C. 80% N.C.
21-7	100% S.C.	50% S.C. 50% N.C.	20% S.C. 80% N.C.
21-8	20% S.C. 80% N.C.	50% S.C. 50% N.C.	100% N.C.
21-9	100% N.C.	40% C 60% N.C.	100% N.C.
21-14	100% N.C.	100% N.C.	100% N.C.
21-20	40% S.C. 60% N.C.	100% N.C.	100% N.C.
21-27	20% S.C. 80% N.C.	100% N.C.	100% N.C.
21-29	100% N.C.	50% S.C. 50% N.C.	100% N.C.
21-31	100% N.C.	50% S.C. 50% N.C.	0% S.C. 40% N.C.
21-77	20% S.C. 80% N.C.	100% N.C.	100% N.C.
21-78	100% S.C.	100% N.C.	100% N.C.
21-80	100% N.C.	100% C	50% S.C. 50% N.C.
21-92	20% C 80% N.C.	50% S.C. 40% N.C.	50% S.C. 40% N.C.
21-93	10% S.C. 80% N.C.	100% N.C.	100% N.C.
21-96	40% C 60% N.C.	100% N.C.	50% S.C. 50% N.C.
21-98	100% S.C.	50% S.C. 50% N.C.	70% S.C. 20% N.C.
21-42	100% N.C.	40% S.C. 60% N.C.	50% N.C. 50% N.C.
21-67	20% S.C. 80% N.C.	100% N.C.	20% S.C. 70% N.C.
21-69	20% C 80% N.C.	100% N.C.	100% S.C.
21-70	40% S.C. 60% N.C.	70% C 20% N.C.	100% C.

**Key**

C Normal crazing

S.C. Slight crazing

B.C. Badly crazed

N.C. Non crazing

TABLE XVI  
TIME REQUIRED FOR OXIDATION AT 750°C

Laboratory No.	Hours required to oxidize at 750°C	Remarks
2614	2	Very little oxidation necessary
2615	14+	Oxidation required practically nil
2617	9+	Easily oxidized
2619	2	Pretty difficult to oxidize
2620	4	Easily oxidized
2624	5	Quite difficult to oxidize
2625	3+	Oxidation required practically nil
2627	3	Difficult to oxidize
2628	14	Only slightly difficult to oxidize
2629	14	Slight oxidation only required
2630	5	Pretty easy to oxidize
2632	4	Pretty easy to oxidize
2633	22	Pretty difficult to oxidize
2635	4	Pretty easy to oxidize
2636	5+	Slight oxidation only required
2642	5	Pretty easy to oxidize
2647	10	Very difficult to oxidize
2650	4	Easily oxidized
2676	7	Pretty easy to oxidize

TABLE XVI-III  
FUSION POINT  
(PC.E.T.)

No.	Cone	%	No.	Cone	%	No.	Cone
2614	32	.705*	2627	40+	1029	2723	3. + .705
2615	31	.685	2628	31	1028	2724	32
2617	32 +	1.7	273	3. +	1026	2734	37
2619	31	.695	274	3.7	1025	2742	33 + .71.2
2622	33	.720	275	3.	1026	2764	31
2624	31 +	.695	276	32 +	1.12	2769	33
2630	30	.670	2772	3.	.650	2773	32 + 1712

\* Revised scale, U. S. Bureau of Standards.  
Note: All clays washed through 100 mesh

### General Geological Section Southern Saskatchewan

That the geological position of the Saskatchewan ball clays may be noted the following outline or general section\* is given:

Glacial	Surface	
Cypress Hills	Oligocene	
Ravenscrag	Port Union	Tertiary
Whitemud	(Eocene)	
Batoche		
Fayre, Foothills	Montana	Cretaceous
Belly River		

\*Davis, 1916, Clay Resources of Southern Saskatchewan.

## Geological Structure of Districts

	Pl.	In.		Pl.	In.	
2624						
Glacial and Ravencrag	26-40	0	2624, dark gray gritty clay (black siltstone)	5	0	
Lignite	3	0	Yellowish to gray shaly clay	4	0	
2614, light gray plastic clay	0	0	Lead gray sand; clays (Estevan)	-		
White plastic clay	0	0				
Iron streak						
Unknown						
2625			2625			
2627			Glacial and Ravencrag	0-30	0	
Glacial and Ravencrag	15	0	2723, grayish purple plastic Lignite	10	0	
Lignite	1	0	White clay, iron-stained	5	0	
2617, purple to yellowish gray plastic	17	0	Grayish sandy clay, black stems	0	0	
(iron stain and concre- tions)			Dark rusty shale	2	1	
2618, white plastic clay (fine concretions)	10	0	White sandy clay	12	0	
Lead gray sandy clays (Estevan)	-		Unknown			
2628			2724*			
Glacial and Ravencrag	25	0	Alluvial and Ravencrag	1-4	1	
Lignite	2	0	Lignite clay	2	0	
Purplish to dark clay			Purplish to dark clay	1	0	
Light gray nearly white clay			Light gray nearly white clay	1	0	
2619, light gray purplish tough plastic clay (iron-stained)	4	0	2714, blue plastic clay, gritty	2	0	
Gray clay fine iron concre- tions	5	0	Congl sandy blue clay	4	0	
Lead gray sandy clays (Estevan)	-		Unknown			
2629			* Taken from a test pit in valley, clay carries under deep cover in valley sides.			
2630			2725			
Glacial and Ravencrag	10-20	0	Glacial and Ravencrag	10-20	0	
Lignite	4	0	273 gray clay, purplish tint	4	0	
Unknown			Unknown			
2631			* From drift mine:			
Glacial and Ravencrag	15	0	2726			
Lignite	0	0	Glacial and Ravencrag	25	0	
2632, purple plastic clay (iron concretion)	8	0	Lignite	2	0	
Silty shale, light brown	3	0	Dark gray clay	2	0	
Lignite	1	0	Light gray clay	2	0	
Dark gray gritty clay	4	0	Iron stain (discarded)	0	10	
Gray sandy clay	2	0	Grey clay	5	0	
Unknown			(Iron stain near base)			
2633*			2727			
Glacial and Ravencrag	4-20	0	Dark nearly black clay	1	0	
2634, purple plastic, grayish	4	0	Grey greasy clay	2	1	
Unknown			* Gray to dark choco- late clay			
From drift mine			277			
2635			Glacial and Ravencrag	0-30	0	
2637			2728, black plastic clay	2	0	
Glacial and Ravencrag	20	0	2729, gray clay purplish tint	4	0	
Lignite	2	0	White plastic, many iron concretions	4	0	
2637, light gray gritty clay	0	0	2730, white sandy clay	20	0	
2638, light gray gritty clay	0	0	Lead gray sandy clays (Estevan)	?		
White sandy clay coarse	0	0				
grain	14	0				
Unknown						
2639						
Glacial and Ravencrag	25	0				
Sandy gray shale	12	0				
Lignite	1	0				
Yellowish shaly clay	4	0				

	Pl.	In.		Pl.	In.
2749*					
Glacial and Ravencrag	0-40	0	2749, grayish with purple tint (Nodular iron concretion)	6	0
Yellowish shale (Ravencrag)	6	0			
Lignite	0	6	Yellowish iron-stained gray	7	0
2843, bluish clay, dries gray	4	0	White plastic, fine-iron concretions	10	0
Unknown			Lead gray sandy beds (Estevan,		
* From a test pit					
2827			2749*		
Glacial and Ravencrag	70	0	Glacial and Ravencrag	5-40	0
Lignite	2	0	Yellowish shale (Ravencrag)	6	0
Purplish plastic clay	2	0	Lignite	3	0
Eros. seam	0	0	2742, bluish clay dries gray	4	0
Grayish plastic clay	2	0	Unknown		
Black plastic clay	2	0	" From a test pit		
Gray to dark chocolate clay	2	0			
Dark chocolate to black clay	1	0	2747		
Dark clay	3	0	Glacial and Ravencrag	30	0
Dark clay			Lignite	2	0
Unknown			Purplish plastic clay	2	0
2753			Iron seam	0	10
2754			Grayish plastic clay	2	0
Glacial and Ravencrag	15	0	Black plastic clay	2	0
Lignite	1	0	Gray to dark chocolate clay	2	0
2770 Dark chocolate to purple	1	0	2767 late clay	2	0
Lighter shade (Nodular iron concretion)	2	0	Dark chocolate to black clay	1	0
			Dark clay	3	0
			Unknown		

### Summary

The ball clays, the physical properties of which have been here described differ both from the English and American ball clays in several respects, though their plasticity and working properties are the equivalent of the best clays of this type.

The water of plasticity of the Saskatchewan clays averages about 28% on the wet basis. This figure is somewhat lower than the normal for either American or English clays, it no doubt explains in a measure the lower drying shrinkage of the Saskatchewan clays and indicates the existence of a different structure.

The remarkably high strength in the raw state of the Saskatchewan clays is noteworthy. On comparison with figures given by Parmelee and McVay<sup>12</sup> it is to be observed that the three Saskatchewan clays of highest strength exceed the three strongest American and English clays by 20-4%. Further, in a similar comparison with figures by Fortwell<sup>13</sup> the difference in favor of the Saskatchewan clays is 74-4%. Therefore, in cases where high bonding power strength in the raw or bisque state is desirable, the Saskatchewan clays are of much interest.

<sup>12</sup> *Amer Ceram Soc., 10 (8), 696-698 (1927).*

<sup>13</sup> See reference 10, p. 5.

On the other hand they are more inclined to crack in drying than the standard clays of this type, a fact to be taken into consideration in determining the amount it is safe to use in a green body.

From reliable sources the firing shrinkage of ball clays in actual use at cone 8 is about 2½%. The Saskatchewan clays here reported on as a rule, show a shrinkage lower than the above figure at the same temperature. This may be accounted for in part by different firing conditions.



FIG. 3

A number of the Saskatchewan clays remain somewhat more open at this cone.

Through a study of the volume shrinkage porosity curves it is noticeable that the Saskatchewan clays have on the whole a lower shrinkage than either the American or English ball clays the rate of change being more nearly that of the English clays. On the other hand the Saskatchewan clays, with one exception, show a higher porosity than the English clays between cones 6 and 12 and, in addition, there is a slight continuous change from cone to cone in the Saskatchewan clays while the English clays remain constant. In comparison with Tennessee ball clays the Saskatchewan clays show slightly lower porosity changes between cones 6 and 12, and materially less than those of the Kentucky clays.

It is to be noted among the Saskatchewan clays that eight of them are white or nearly white at cone 4 and of these three remain white at cone 8. Nine are light cream at cone 4 and of these seven remain of the same shade at cone 8. Thus, where a white body is desirable some of the Saskatchewan clays are of interest, and especially so in thin section ware requiring maximum strength in the raw. One difficulty is met with, however through the presence of more or less dark specks due to some iron-bearing mineral. While traces were found in all samples, five of them



FIG. 4

have proven sufficiently free of speck to permit of their use in large quantities in the U. S. whiteware industry during the past three years. Further study with reference to the removal of the objectionable specks in the Saskatchewan clays is to be recommended.

The chemical analyses of the Saskatchewan clays indicate that they carry more free silica than the average English and American ball clays. Generally speaking the average pottery ball clay in the dry state fluctuates around 33% alumina content. The present clays, with one exception, carry from 28.8 to 30.8% of alumina.

Though the fusion point of ball clays may be of little interest to the manufacturer of whiteware, they were obtained in the present work for each of the clays and the findings have proved of interest in that eight of them have a P.C.E. of cone 32 or more. This quality, in connection with their high strength in the raw state, makes them worthy of study as bond clays for various lines of refractories.

The time required for the oxidation of ball clays is not normally of much importance, since in the manufacture of whiteware other body constituents are nearly always introduced, which open up the structure. Of the clays tested, however, 2723 is the only one which might lead to manufacturing difficulties in the firing of the ware.

**Acknowledgments** The work here presented has been made possible through the unanimous cooperation of the Department of Railways, Labour, and Industries of the Saskatchewan Government and the Ceramic Department of the University. The author desires to express his appreciation of the hearty support of T. M. Molloy, Deputy Minister, Department of Railways, Labour and Industries, throughout the entire work, also to S. Matthews for the efficient and laborious laboratory work carried out under his supervision. Acknowledgment is also made of the services of Jas. R. Craig, J. C. Worcester, W. H. Phipps, and others, extending over a period of two years. It is also a pleasure to mention A. V. Kleininger who gave helpful suggestions throughout the work, and for the supply of commercial whiteware glaze used in the glaze studies.





